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MANIPULATION OF MICRO SCALE PARTICLES IN AN OPTICAL TRAP USING INTERFEROMETRY

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Abstract

This research shows that micro particles can be manipulated, via interferometric patterns superimposed on an optical tweezers beam. Interferometry allows the manipulation of intensity distributions, and thus, force distributions on a trapped particle. To demonstrate the feasibility of such manipulation, 458 nm light, from an argon-ion laser, was injected into a Mach Zender interferometer. One mirror in the interferometer was oscillated with a piezoelectric phase modulator. The light from the interferometer was then injected into a microscope to trap a 9.75 μm polystyrene sphere. By varying the phase modulation, the sphere was made to oscillate in a controlled fashion.

Introduction

With the rapid growth of interest in nano technology has come the possibility of manually constructing or interrogating nano structures held in optical tweezers. However, using optical tweezers for direct, high resolution control of nano scale particles is untenable given the diffraction limits of the system. The minimum diameter of a focused spot in such a system is given by the following equation:

$$d_{\min} = 1.22\lambda / N.A.$$

where d_{\min} is the minimum diameter of the focused spot, and $N.A.$ is the numerical aperture of the objective. For $N.A. = 1.25$, $\lambda = 458 \text{ nm}$, $d_{\min} \approx \lambda$. Such a relatively large focus precludes the high-resolution manipulation and measurement of anything with size on the order of the wavelength of light used or smaller (1).

Complicating direct manipulation of nano particles is the relative complexity of current optical tweezers configurations. Manipulation of particles in one plane currently requires either coupling microscope stage movement with vertical translation of the trap or the use of at least two trapping beams: one to hold the particle, the other to manipulate it. Multiple beam trapping requires coordinating active beam steering modalities—piezo driven mirrors, acoustic beam steerers, et al.—for each beam. The size and complexity of both methods will limit their ability to manipulate nano particles.

The objective of this research, performed at NASA Glenn Research Center, was to qualitatively prove viable a technique for manipulating a micron scale tool, via interferometry. Such a technique would simplify an apparatus by requiring only a single

beam to manipulate a tool. An appropriate diffraction solution would allow the translation of a tool across the objective's field of view, without having to move the microscope stage. Moreover, such a solution would reduce the complexity of the optical train, thus reducing apparatus size and complexity.

Experimental Method

The first step in this project was to assemble and optimize an optical tweezers apparatus (Figure 1), and the second step was to perfect the trapping technique.

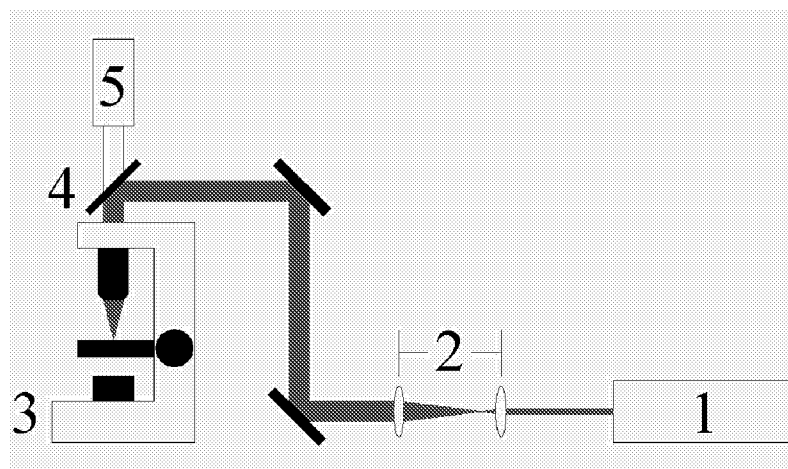


Figure 1. 1. Laser; 2. Beam Expander; 3. Microscope; 4. Dichroic Filter; 5. CCD Camera

To this end, 190 mW of 458 nm light from a 5 W Argon ion laser (2) was collimated and injected into a microscope (3), via a yellow, subtractive dichroic filter (4). The dichroic filter was inserted into the light path such that it reflected the laser beam into the microscope but prevented laser light from returning to the digital camera. A 100X, oil-immersion objective, N.A. 1.25 (5) was used to focus the laser on the 9.75 μm polystyrene spheres in suspension (6). The spheres were contained in a well, constructed by sandwiching two, 100 μm thick, parafilm strips between a microscope slide and a 0.17 mm coverslip (Figure 2).

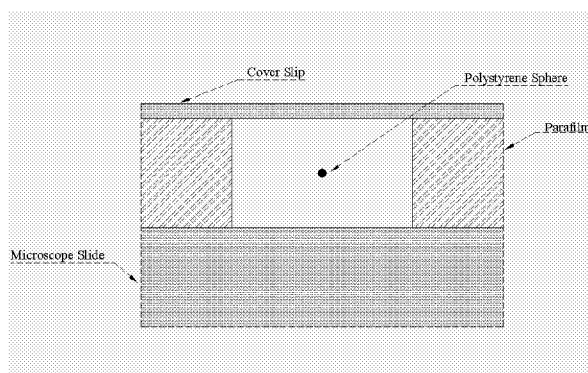


Figure 2. Trapping Well

The sphere suspension was entrained into the well via capillary action, and the well was sealed with grease. A CCD video camera (7) was used in place of the microscope head to image the trapped particles.

In the third step of this project, a Mach Zender interferometer was inserted into the optical path, between the collimator and the microscope (Figures 3, 4).

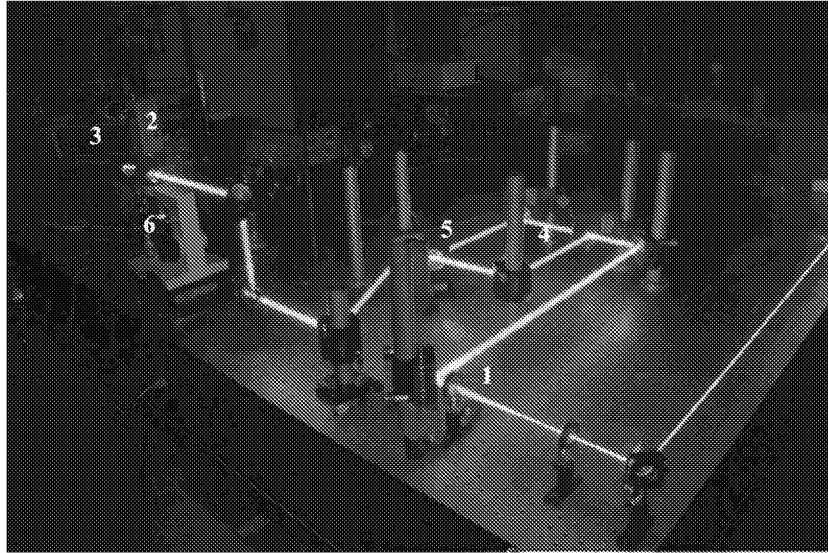


Figure 3. 1. Collimator; 2. CCD Video; 3. Ramp Generator; 4. Interferometer; 5. Piezo Mirror; 6. Particle Well, Microscope Stage, Objective

The interferometer was adjusted to provide a finite fringe pattern. One mirror in the interferometer was replaced with a mirror driven on three axes by piezo electric actuators.

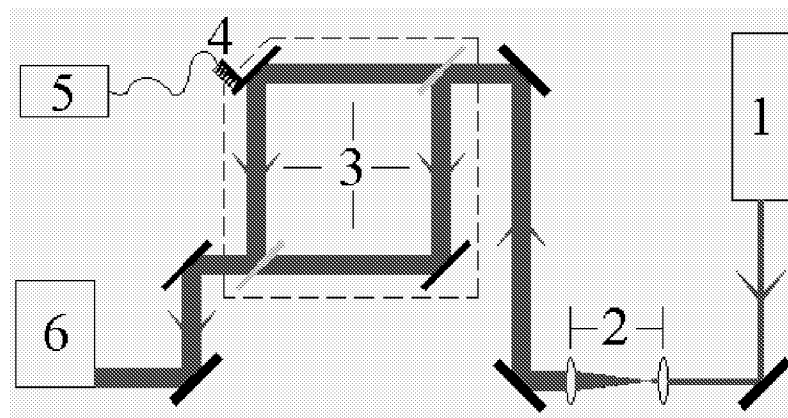


Figure 4. 1. Laser; 2. Beam Expander; 3. Mach Zender Interferometer; 4. Piezo Mirror; 5. Ramp Generator; 6. Microscope and CCD Camera

This driven mirror provided phase modulation of the interference pattern and was controlled by a ramp generator (8), along only one axis. The behavior of trapped particles was observed as a function of ramp duration, where the duration was varied from 100 ms to 1000 ms on the ramp generator. The objective was to find a ramp duration that allowed the easiest viewing of particle movement.

Results and Discussion

The first successful trap was established at a laser power of 190 mW (60 mW at the particle well coverslip). The trap plane differed significantly from the focal plane of the

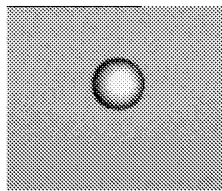


Figure 5. *Untrapped Sphere*

camera, being 10 μm – 15 μm above the camera focal plane, as measured by the scale on the microscope's vertical translation knob. It was felt that this was a result of significant spherical aberration in the microscope objective. The microscope objective used was not apochromatic and was only a semi-plan objective. Further, it is known that spherical aberration can be exacerbated as an image is projected back through a non-infinity corrected objective to the back aperture image plane. This effect is worsened if components are introduced into the path between the objective and the back aperture image plane. Due to the distance between the viewing plane and the trapping plane, trapped particles were not directly visualized, but instead were seen as an Airy pattern projected onto the bottom of the well (Figure 6).

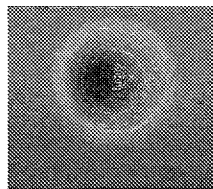


Figure 6. *Trapped Sphere*

Subsequent traps were achieved at a laser output of 86 mW (approximately 25 mW at the coverslip.).

With the Mach Zender interferometer in place, it was noted that with a laser output of 80 mW, the power at the coverslip was 78 percent less than when there was no interferometry loop. Nevertheless, a trap could still be formed, and it performed nearly identically to the traps formed without the interferometer. With the ramp generator driving the mirror, motion could be seen in the Airy pattern created by the sphere. The movement was best visualized at ramp durations between 200 ms and 500 ms. At these durations, the sphere's movement did not coincide with the interference pattern movement. It appeared that the sphere's motion had a sharp rise, matching the ramp

generator input, which was followed by a slow relaxation period. This seemed to indicate that actual induced movement was being witnessed since the ramp generator did not exhibit a similar “relaxation” period.

Concluding Remarks

This project has demonstrated the viability of using interferometry to manipulate a micro scale particle in an optical trap. The results further indicate that trap strength is sensitive to spherical and chromatic aberrations in the optical train. Finally, it is apparent that before progressing to the next phase, coated optics, tuned to the specified wavelength need to be used to improve light transmission throughout the optical train, and an infinity corrected microscope objective is necessary to bring the viewing and trapping planes into phase.

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